AN OVERVIEW OF THE JOINT FAA/NASA AIRCRAFT/GROUND VEHICLE RUNWAY FRICTION PROGRAM

by

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INTRODUCTION

THERE IS AN IMPERATIVE NEED for information on runways which may become slippery due to various forms and types of contaminants. Experience has shown that since the beginning of "all weather" aircraft operations, there have been landing and aborted takeoff incidents and/or accidents each year where aircraft have either run off the end or veered off the shoulder of low friction runways. From January 1981 to January 1988, more than 400 traction-related incident/accidents have occurred according to Federal Aviation Administration (FAA) and National Transportation Safety Board (NTSB) records. These cases have provided the motivation for various government agencies and aviation industries to conduct extensive tests and research programs to identify the factors which cause the runway friction to be less than acceptable. The continued occurrence of aircraft takeoff and landing accidents emphasize the need for improved measurement techniques and inspection procedures related to tire and runway conditions. NASA Langley's Landing and Impact Dynamics Branch is involved in several research programs directed towards obtaining a better understanding of how different tire properties interact with varying pavement surface characteristics to produce acceptable performance for aircraft ground handling requirements. The following sections of this article describe one such effort, which was jointly supported by not only NASA and the FAA but by several aviation industry groups including the Flight Safety Foundation, is described.

SCOPE OF PROGRAM

The Joint FAA/NASA Aircraft/Ground Vehicle Runway Friction Program is aimed at obtaining a better understanding of aircraft ground handling performance under a variety of adverse weather conditions and to define relationships between aircraft and ground vehicle tire friction measurements. Major parameters influencing tire friction performance such as speed, contaminant type and amount, test tire inflation pressure, and runway surface texture were evaluated during the test program. These tests involved a specially instrumented NASA B-737 aircraft and an FAA B-727 aircraft shown during test runs in figure 1. Several

different ground friction measuring vehicles used during the program are shown in figure 2. The diagonal-braked vehicle developed by NASA measures locked wheel sliding friction values. The FAA mu-meter trailer monitors side force variation on two tires yawed to an included angle of 15 degrees. Both the surface friction tester automobile and Swedish BV-11 skiddometer trailer measure tire braking friction near the peak of the tire friction/slip ratio curve. A relatively new runway friction tester van also measures peak tire braking friction. Both a Tapley meter and a Bowmonk brakemeter were installed in the runway condition reading (RCR) vehicle to indicate vehicle braking deceleration levels under snow and ice conditions. With these known differences in ground vehicle test tire operational modes, different levels of tire friction measurements were expected, and obtained, for the same runway surface condition. Between June 1983 and March 1986, tests were performed on 12 different concrete and asphalt runways, grooved and nongrooved, including porous friction coarse, under dry, truck wet, rain wet, snow-, slush-, and ice-covered surface conditions. A limited assessment of some runway chemical de-icing treatments was also obtained. Over 200 test runs were made with the two transport aircraft and over 1100 runs were made with the different ground test vehicles. Most of the dry and the truck wet runway surface test runs were performed at NASA Wallops Flight Facility in Virginia and the FAA Technical Center airport in New Jersey. A limited number of rain wet tests were performed at Langley Air Force Base, Virginia, Pease Air Force Base, New Hampshire, and Portland International Jetport, Maine. All the winter runway test conditions were evaluated at Brunswick Naval Air Station in Maine. The test procedure for wet runway conditions was to make ground vehicle runs before and after each aircraft braking run. For the winter runway conditions of compacted snow and solid ice, a series of ground vehicle runs were made immediately following the aircraft test runs on each surface contamination condition. At loose snow depths equal to or greater than 2 in., test runs with the two trailer devices were suspended because constant speed could not be maintained.

TEST RESULTS AND DISCUSSION

A substantial tire friction database has been collected during this Joint FAA/NASA Runway Friction Program with extensive data reduction and analysis being accomplished at NASA Langley. All of the runway friction data will be discussed and analyzed in a soon-to-be-published NASA technical report that has undergone both FAA and NASA technical reviews. Only a very limited amount of aircraft and ground vehicle friction data are presented herein to indicate some of the major test findings and data trends.

Wet runways - The range of B-737 aircraft and ground vehicle friction measurements obtained on nongrooved and grooved surfaces under truck wet conditions is shown in figure 3. As expected, the grooved runway surface friction data is significantly greater than the nongrooved data, particularly at the higher speeds. Most of the ground vehicle friction values were higher than those developed by the B-737 aircraft because of differences in braking test mode, tire tread design, and tire inflation pressure. When these major factors are properly considered using techniques and methodologies being developed at NASA Langley, aircraft wet runway braking performance can be estimated from ground vehicle friction measurements. The relationship between actual braking friction coefficient for the B-737 and estimated braking friction coefficients of the airplane obtained from the ground vehicle measurements is shown in figure 4. For most of the ground vehicle friction measurements, the estimated aircraft performance is in good agreement with the actual measured aircraft braking friction level. The available data suggest that the ground vehicle friction data for wet runway conditions can estimate aircraft tire friction performance to within about 15 percent of the actual measured aircraft friction values and in some cases, within 5 percent. The relationship between ground vehicle estimated and actual aircraft tire friction values will vary with changes in wetness conditions. Hence, ground vehicle friction measurements should be taken on a runway for a range of wetness conditions related to different precipitation rates and surface winds.

Snow- and ice-covered runways - A comparison of B-737 aircraft braking performance for snow- and ice-covered runways as well as dry, truck wet, and flooded conditions is given in figure 5. The range of aircraft effective friction coefficients is from nearly 0.5 on dry runways to 0.05 on the solid ice surface at Brunswick Naval Air Station (BNAS). Similar results were obtained during the B-727 aircraft tests. For compacted snow- and ice-covered conditions, the friction measurements obtained with the various ground test devices indicated that forward speed had little effect on the magnitude of the friction values. Furthermore, the friction values obtained from each vehicle showed no significant difference between compacted snow- and ice-covered conditions. The Tapley and Bowmonk meters were both installed in the Navy runway condition reading vehicle and the manually recorded friction values for each instrument were in close agreement for a given test run. Figure 6 provides a listing of the range of ground vehicle friction values obtained for compacted snow- and ice-covered runway conditions. Tire conditions, ambient temperatures, and test speeds are indicated in the notes accompanying the figure. Qualitative verbal braking action terms namely, excellent, good, marginal, and poor, were used to identify four distinct levels or ranges in friction readings for each device. In general, the excellent friction readings were close to some wet surface values, e.g. 0.5 and above, whereas, the poor friction readings were normally below a friction level of 0.25. The BV-11 skiddometer and the surface friction tester values were similar as expected since the test tire and braking slip operation were identical. The range of friction values at each of the four qualitative levels is nearly the same for the mu-meter, Tapley meter, runway friction tester, and the Bowmonk meter. Slightly higher friction values were obtained with the surface friction tester and the BV-11 skiddometer probably due to the use of a higher test tire inflation pressure and the use of a grooved tread pattern on the tire instead of a smooth tread.

The range of aircraft effective braking friction coefficient values with ground speed for compacted snow- and ice-covered runway conditions is shown in figure 7. The data symbols and line codes denote the different test conditions and aircraft. The best fit, least

squares, linear curve for the compacted snow-covered surface friction data, denoted by the solid line, is nearly four times greater than the data from the glare ice-covered surface denoted by the dashed line. These aircraft results differ from the ground vehicle measurements which indicated no significant difference between compacted snow-covered runway condition and the solid ice-covered condition. The difference in braking performance shown in figure 7 between the two test aircraft under these winter runway conditions was considered insignificant. The aircraft braking performance on the snow-covered and ice-covered surfaces was relatively insensitive to ground speed variations which was also found for the ground vehicle measurements.

Since each test aircraft indicated a significant difference between the compacted snow-covered and ice-covered surface conditions, two ranges or means of aircraft braking friction data were selected to define the relationship with the ground vehicle friction measurements. The resulting aircraft and ground vehicle friction correlation chart is shown in figure 8 where the compacted snow-covered and ice-covered surface condition is delineated for the two aircraft. For the compacted snow-covered surface condition, an aircraft effective braking friction coefficient value of 0.21 was selected for the highest braking action level and 0.12 was used for the lowest braking action level. An effective braking friction coefficient range from 0.055 to 0.01 was selected for comparable aircraft braking action levels on the ice-covered surface condition. The dashed line in figure 8 depicts comparable values for other ground vehicles and the two aircraft/surface conditions for an RCR value of 15.

From an aircraft operator's viewpoint, these values of friction for a snow- or ice-covered runway must be considered in respect to the actual runway geometry and such environmental conditions as pressure/altitude, winds, and ambient temperature at the time of a particular aircraft operation. It should also be recognized that aircraft operations can occur on runways which have a nonuniform mixture of compacted snow-covered area and exposed solid ice-covered surfaces. In such circumstances, additional ground vehicle friction measurements need to be taken to adequately determine average friction numbers for each

runway. How well this established relationship between aircraft and ground vehicle friction values remains for other aircraft types is somewhat questionable although the available data tends to suggest a similar relationship. The use of actual friction numbers in place of qualitative braking action terms is strongly recommended because with experience, these runway friction values measured by a ground vehicle will provide the pilot a more precise and accurate gage on the safety margins available for landing on a given runway. Proper and timely use of snow removal equipment and runway chemical treatments to minimize and/or remove snow and ice contaminants is still recognized as a necessity to return to dry runway friction levels as soon as possible.

CONCLUDING REMARKS

An overview of the Joint FAA/NASA Aircraft/Ground Vehicle Runway Friction Program has been given. A substantial tire friction database has been collected from tests with two instrumented transport aircraft and several different ground test vehicles on a variety of runway surfaces and wetness conditions. A better understanding of the major factors influencing tire friction performance has been achieved. The relationships defined between the different ground vehicles and between ground vehicle and aircraft tire friction performance are very encouraging. Greater usage of ground vehicle friction measurements at airports is strongly encouraged to define runway surface maintenance requirements and to monitor current runway friction levels under adverse weather conditions.

In October 1988, a Runway Friction Workshop was held at NASA Langley to discuss with the aviation community the preliminary test results from the joint program and to obtain their comments and recommendations. Eighteen formal presentations were made to approximately 80 attendees representing U. S., Canadian, and Swedish government agencies, airframe manufacturers, airlines and pilots, airport managers, ground test vehicle manufacturers/suppliers, and aircraft tire and brake companies. Separate presentations were given concerning runway friction work being conducted in Sweden, England, France, Japan,

and Canada. Based upon workshop discussion, the Joint Runway Friction Program draft report has been modified and improved. Future plans include a Joint NASA/FAA Surface Traction Program using the Aircraft Landing Dynamics Facility at Langley to evaluate radial-constructed transport aircraft tires. Work in designing a new standardized form for use at all U. S. airports for reporting and documenting ground vehicle/aircraft friction data will be initiated. Additional meetings with aviation industry representations are planned at FAA Headquarters to discuss how the joint program test findings impact existing advisory circulars, standards, and regulations. With new improved test tires, brake systems, and other equipment becoming available for airport operations in future years, the need is recognized for continued testing of aircraft/ground vehicle runway friction performance.

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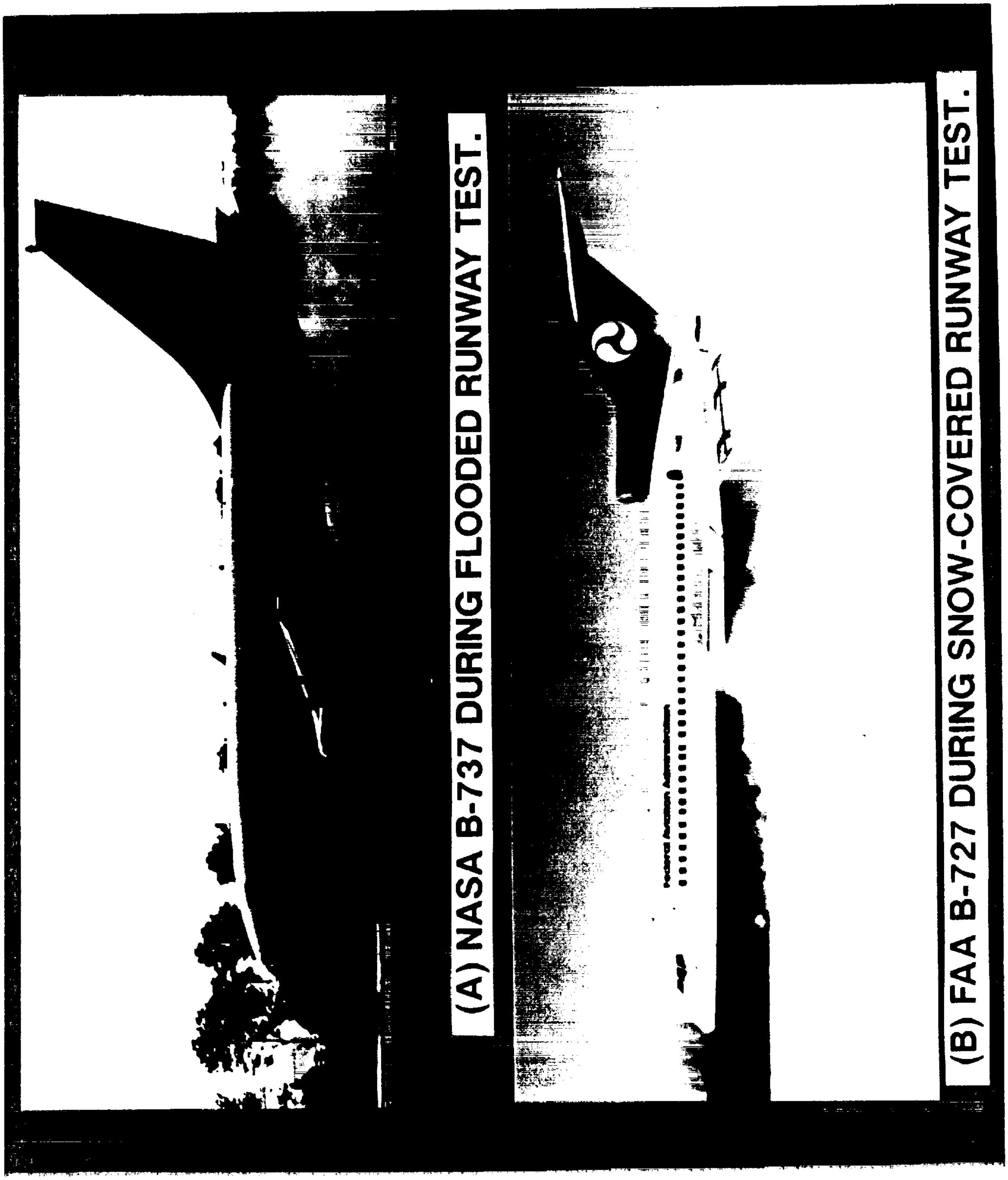

Figure 1.- Specially instrumented test aircraft.

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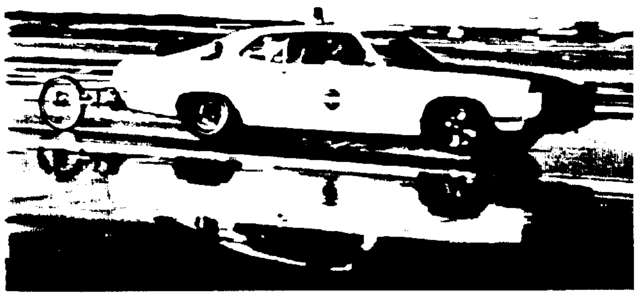
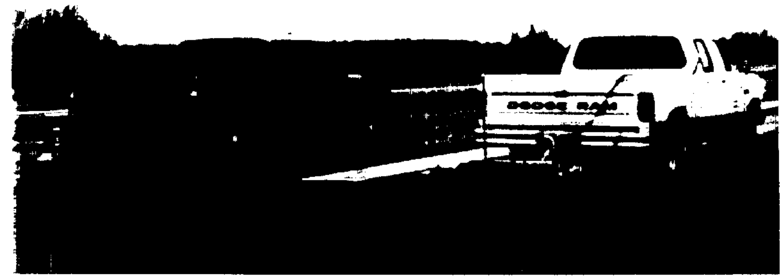
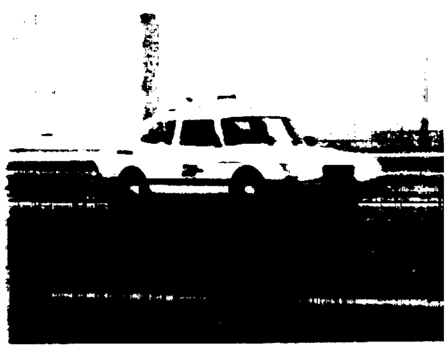


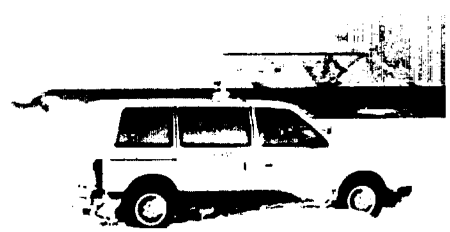
DIAGONAL-BRAKED VEHICLE



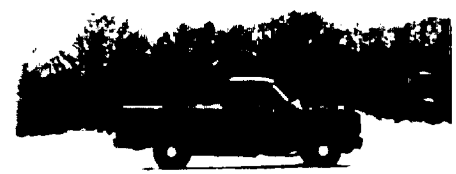
MU-METER & BV-11 SKIDDOMETER TRAILERS



SURFACE FRICTION TESTER



RUNWAY FRICTION TESTER



RUNWAY CONDITION READING VEHICLE

Figure 2.- Ground friction measuring devices.

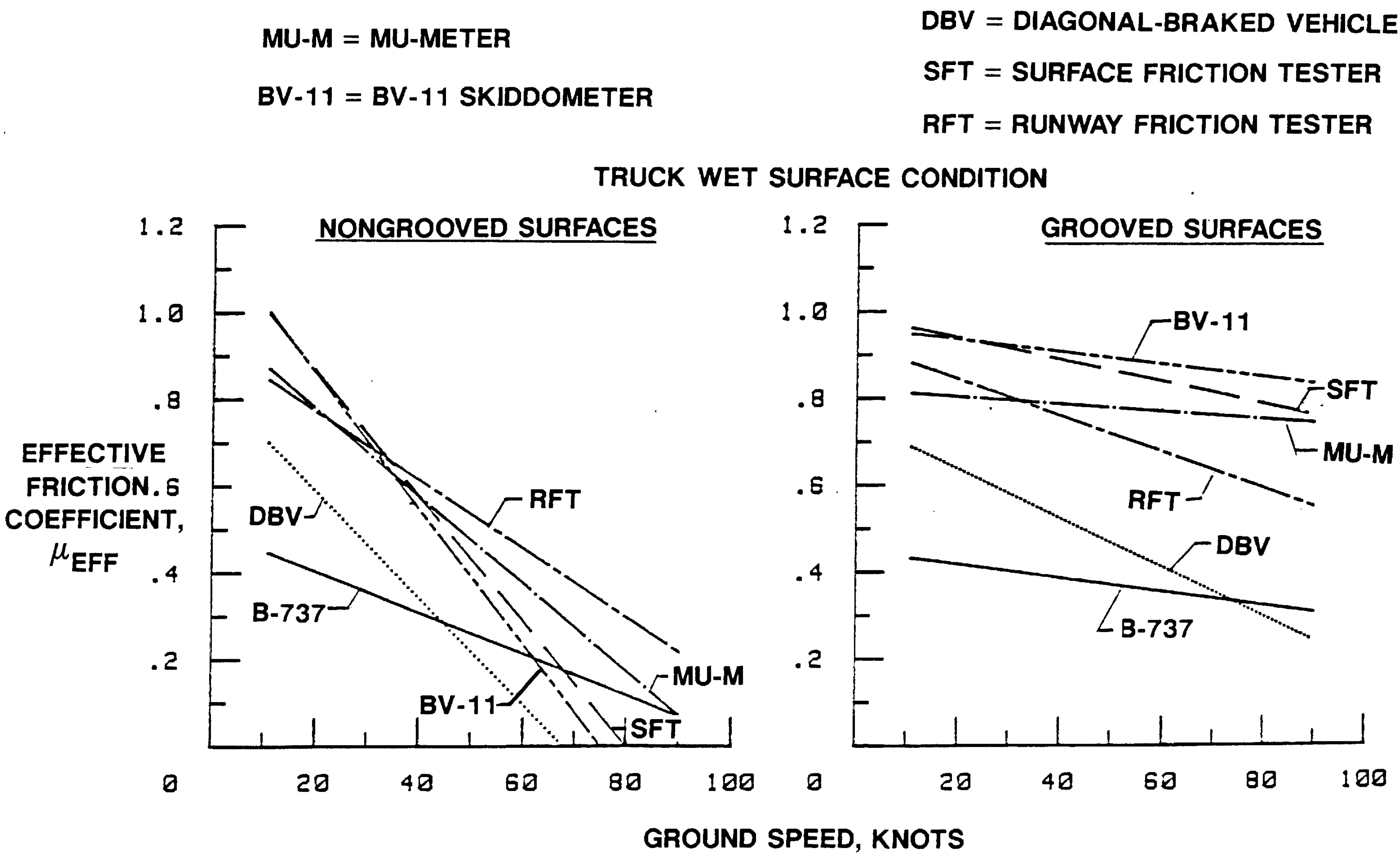


Figure 3.- Range of B-737 aircraft and ground vehicle friction measurements.

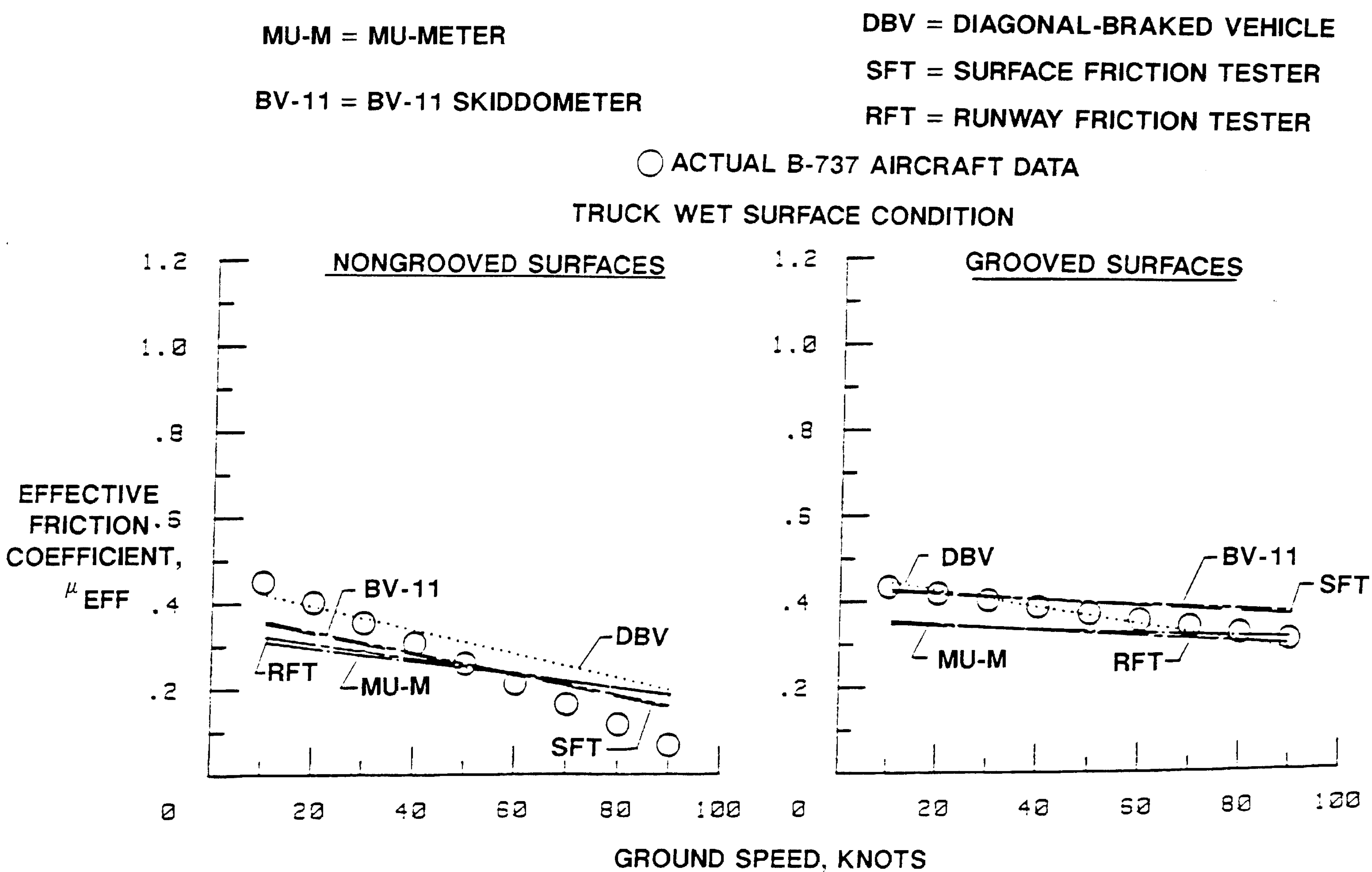


Figure 4.- Relationship between actual and estimated B-737 aircraft braking performance.

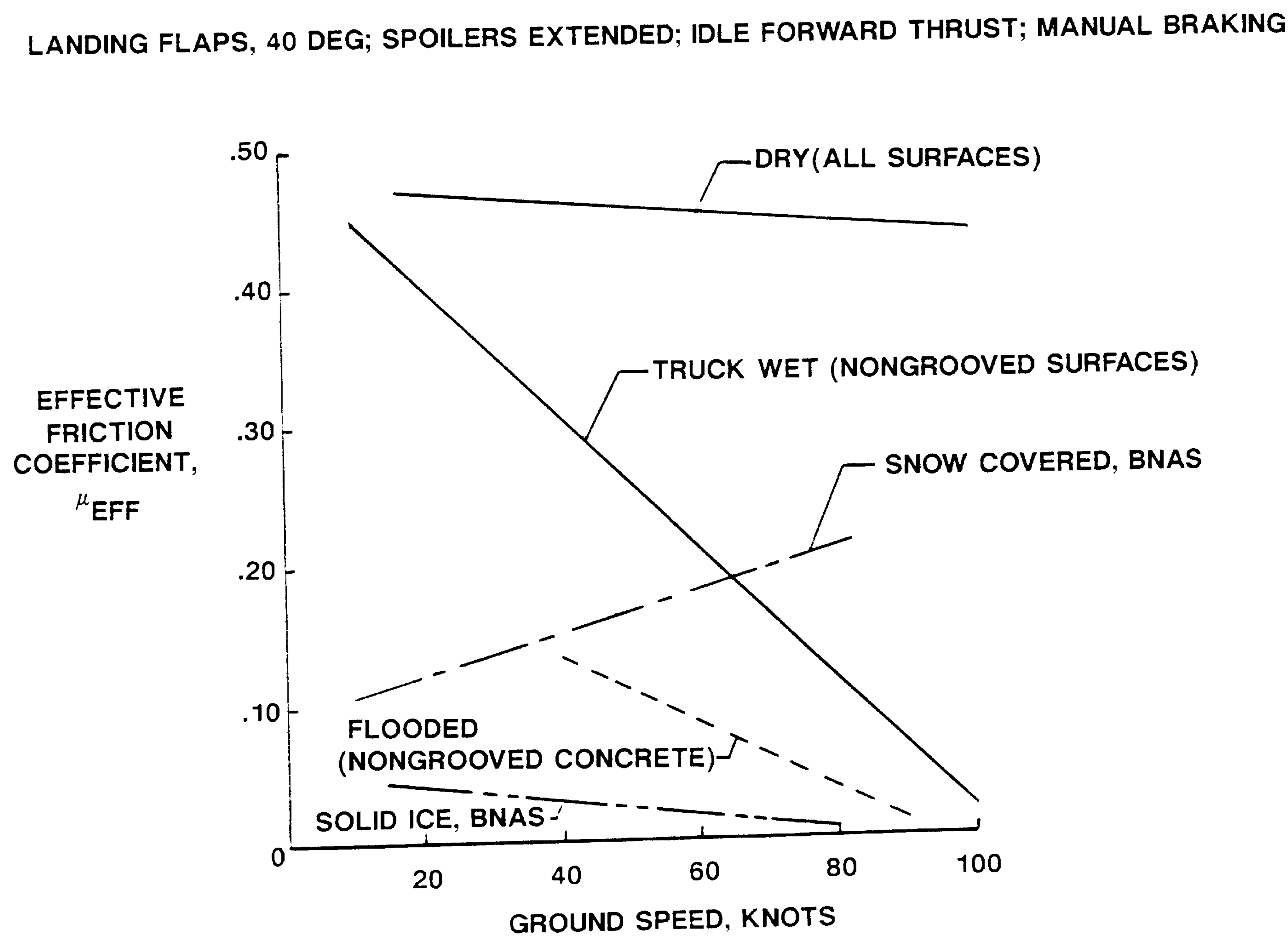


Figure 5.- Comparison of B-737 aircraft braking performance.

Runway Surface Conditions: Compacted Snow and Ice

VERBAL BRAKING ACTION	GROUND VEHICLE FRICTION READINGS						
	MU-METER	TAPLEY METER	RUNWAY CONDITION READINGS (RCR)	BOWMONK METER	SURFACE FRICTION TESTER	RUNWAY FRICTION TESTER	BV-II SKIDDOMETER
EXCELLENT	0.50 and above	0.48 and above	16 and above	0.46 and above	0.58 and above	0.50 and above	0.58 and above
GOOD	0.49 to 0.36	0.46 to 0.35	15 to 12	0.44 to 0.34	0.56 to 0.42	0.48 to 0.35	0.56 to 0.42
MARGINAL	0.35 to 0.26	0.33 to 0.25	11 to 9	0.32 to 0.24	0.39 to 0.29	0.33 to 0.24	0.39 to 0.29
POOR	0.25 and below	0.24 and below	8 and below	0.23 and below	0.27 and below	0.23 and below	0.27 and below

NOTES:

(1) Mu-meter equipped with smooth RL-2 tires inflated to 69 kPa (10 lb/in.^{2})

(2) Runway friction tester equipped with smooth RL-2 tire inflated to 207 kPa (30 lb/in.^{2})

(3) Surf. friction tester and BV-II skiddometer equipped with grooved aero tire inflated to 690 kPa (100 lb/in.^{2})

(4) Ambient air temperature range, -15 to +5^0 C (5 to 41^0 F)

(5) Test speed range, 32 to 97 km/h (20 to 60 mph)

Figure 6.- Ground vehicle friction reading correlation table.

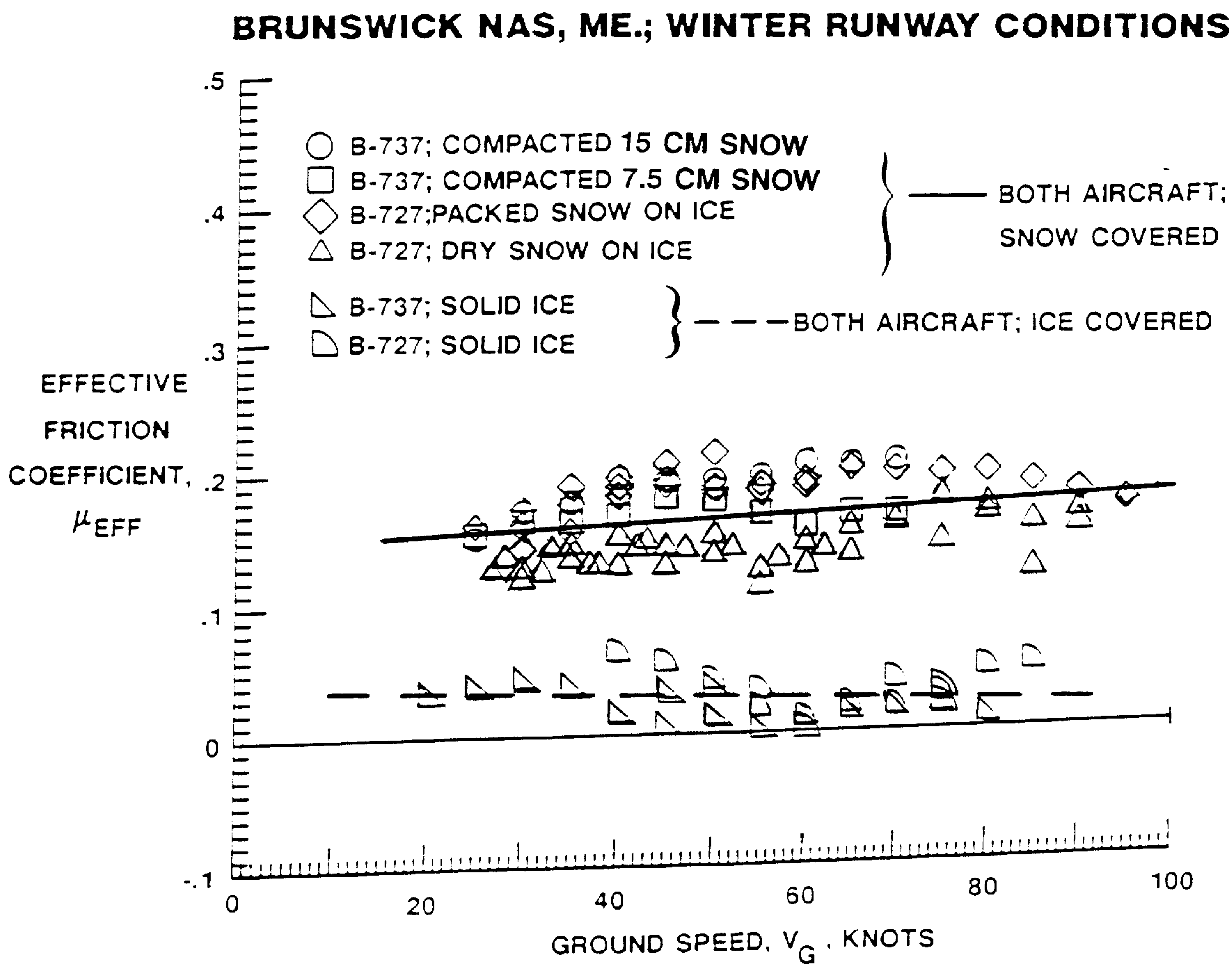


Figure 7.- Aircraft braking friction performance on compacted snow- and ice-covered runways.

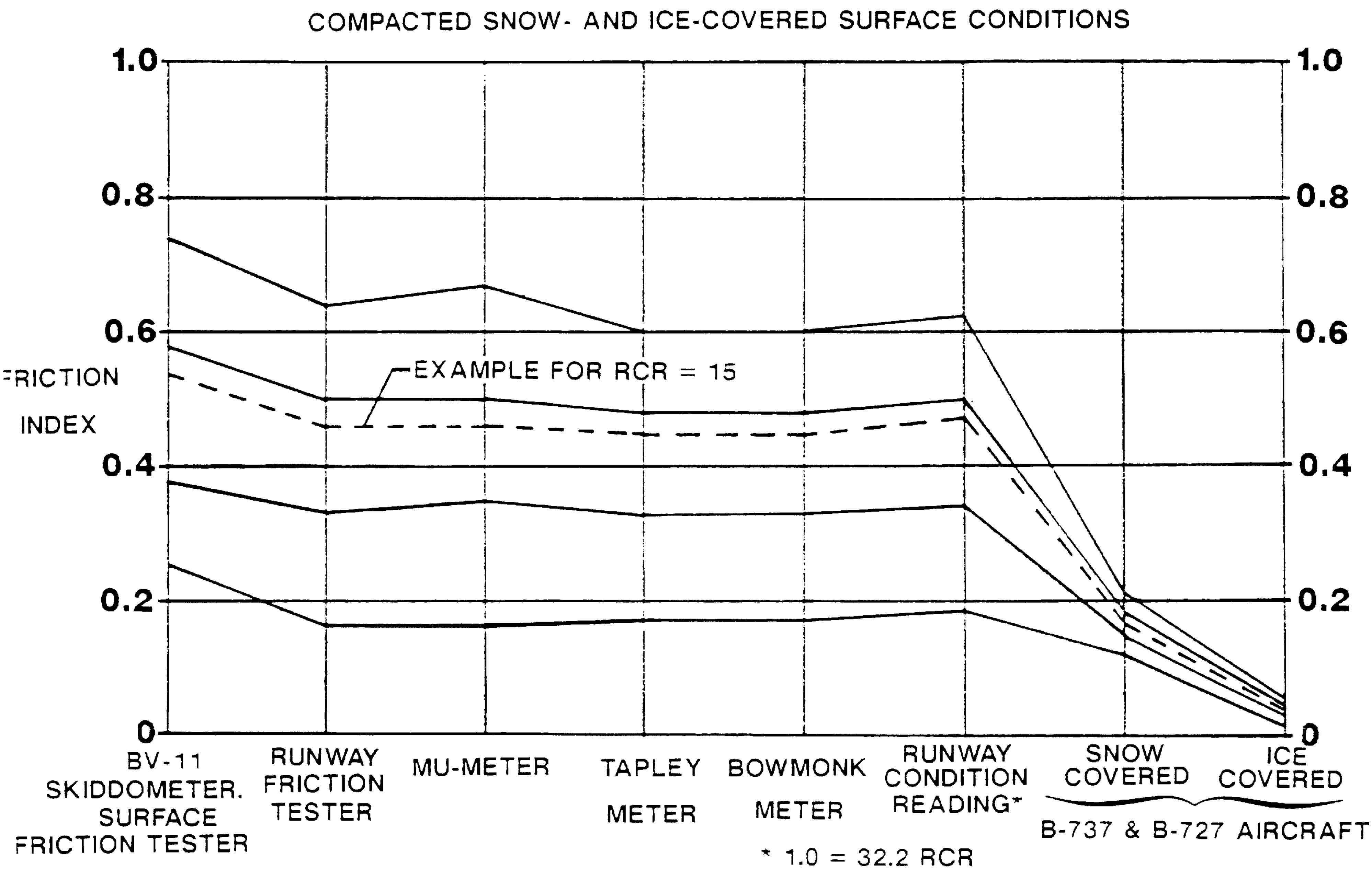


Figure 8.- Aircraft and ground vehicle friction correlation chart.